6
SAB Findings and Recommendations for Nr Data Collection, Risk Management, and Research

This concluding chapter contains the Integrated Nitrogen Committee's findings and its recommendations to EPA. Section 6.1 discusses the need for a comprehensive program to monitor reactive nitrogen. Section 6.2 provides the Committee's overarching recommendations to EPA. Section 6.3 contains suggestions for near-term actions that might be taken by EPA and other management agencies to decrease Nr entering the environment from various sources. Section 6.4 contains specific findings and recommendations corresponding to each of the Committee's four study objectives.

The first objective of the study was to identify and analyze, from a scientific perspective, the problems Nr presents in the environment and the links among them. To accomplish this objective, the Committee examined the flows of Nr within the food, fiber, feed and bioenergy production systems and developed lands in the U.S., paying special attention to the locations within each of these systems where Nr is lost to the environment. The same process was employed for fossil fuel energy production but, since all the Nr formed and released during energy production is lost to the environment, the Committee identified the important energy producing sectors that contribute to Nr emissions. The Committee found that agriculture and domestic use of fertilizers to produce food, feed, and fiber (including bioenergy and BNF) and combustion of fossil fuels are the largest sources of Nr released into the environment in the U.S.

The Committee also examined the fate of the Nr lost to the environment, estimated the amount stored in different systems (e.g., forest soils) and tracked Nr as it is transferred from one environmental system (e.g., the atmosphere) to another (e.g., terrestrial and aquatic ecosystems). Source and fate analyses set the stage for identifying the environmental and human health problems Nr presents, and the links among them. Using the nitrogen cascade, the Committee identified the impacts Nr has on people and ecosystem functions as it moves through each system and contributes to adverse public health and environmental effects, including photochemical smog, nitrogen-containing trace gases and aerosols, decreased atmospheric visibility, acidification of terrestrial and aquatic ecosystems, eutrophication of coastal waters (i.e., harmful algal blooms, hypoxia), drinking water concerns, freshwater Nr imbalances, GHG emissions and subsequent climate change, and stratospheric ozone depletion.

The second objective of the study was to evaluate the contribution an integrated N management strategy could make to environmental protection. To accomplish this objective the Committee identified actions that could be taken to better manage Nr. These actions take into account the contributions of all Nr sources and chemical species that adversely impact human health and environmental systems, and the need to ensure that solving one problem related to Nr does not exacerbate another problem or diminish ecosystem services that support societal demands.

The third objective of the study was to identify additional risk management options for EPA's consideration.In addressing this objective, the Committee identified four major goals for management actions that collectively have the potential to decrease Nr losses to the environment by about 25%. Decreasing Nr emissions by these actions will result in further decreases in Nr-related impacts throughout the nitrogen cascade. The Committee has suggested a number of ways to attain these management goals, including conservation measures, additional regulatory steps, voluntary actions, application of modern technologies, and end-of-pipe approaches. The Committee notes that these are initial but significant actions; however, others should be taken once the recommended actions are completed and assessed, and further opportunities are explored in an adaptive management approach.

The fourth objective of the study was to make recommendations to EPA concerning improvements in Nr research to support risk reduction. The Committee has provided numerous recommendations for additional Nr research to support risk reduction activities.

6.1. Need for Comprehensive Monitoring of Nr

In previous sections of this report the Committee has discussed the importance of monitoring reactive nitrogen in the environment. The Committee recommends establishing a program for comprehensive monitoring of the multiple forms of reactive nitrogen as both stocks and flows as they pass through different media and ecosystems. There are two major reasons for this overarching recommendation. The first purpose of monitoring is to provide the observational data on trends that will inform research into the complexity of the nitrogen cascade to better identify the most effective intervention points to reduce damage to human health and the environment by reactive nitrogen. The second need for monitoring is to be able to assess the effectiveness of policy interventions over time, and to apply the principles of adaptive management. As it becomes clear which strategies and policy instruments are effectively reducing the amounts of Nr entering the environment, and which are ineffective, it will be necessary to modify those interventions in response to the monitoring data. As conditions change (e.g., shifts in the technology of electric power production, new fuels for transportation, changing land use patterns and climate change), the nitrogen cascade will be modified, and the relative importance of sector specific policies will change. Only through comprehensive monitoring will it be possible to manage Nr effectively.

Finding 20: The Committee has determined that an integrated approach to monitoring that includes multiple media (air, land, and water) components and considers a suite of environmental and human concerns related to reactive nitrogen in the environment (e.g., Nr effects, climate change, human health) is needed. Some of the phenomena presented in this report need more definition and verification but, more importantly, as controls are brought to bear on Nr, improvements need to be measured to verify and validate successful management strategies. If the desired improvements are not realized as shown by the collected data, corrective measures will be required. Such an adaptive approach acknowledges the likelihood that management programs will be altered as scientific and management understanding improve.

Recommendation 20: *The Committee recommends that EPA initiate discussions and take action to develop a national, multi-media monitoring program that monitors sources, transport and transition, effects using indicators where possible, and sinks of Nr in keeping with the nitrogen cascade concept. This comprehensive program should build upon existing EPA and state initiatives as well as monitoring networks already underway in other federal agencies such as the U.S. Geological Survey programs and the NADP effort.*

6.2. Overarching Recommendations

Human activities have significantly increased the introduction of Nr into the U.S. environment and, through radical alterations of land use, have eliminated many of the natural features that once may have provided pollutant treatment. While there have been significant benefits resulting from food production, there have also been, and continue to be, major risks to the health of both ecosystems and people due to the introduction of Nr into the nitrogen cascade.

In its 1990 report, *Reducing Risk,* the Science Advisory Board recommended that the EPA increase its efforts to integrate environmental considerations into broader aspects of public policy in as fundamental a manner as are economic concerns. Other federal agencies often affect the quality of the environment, e.g., through the implementation of tax, energy, agricultural, and international policy, and EPA should work to ensure that environmental considerations are integrated, where appropriate, into the policy deliberations of such agencies. In the current era of increasing responsibilities without commensurate budgets, intergovernmental cooperation, partnerships and voluntary programs have become vital tools for agencies needing to stretch their resources to fulfill their missions.

Optimizing the benefits of Nr, and minimizing its impacts, will require an integrated nitrogen management strategy that not only involves EPA, but also coordination with other federal agencies, the States, the private sector, universities, and a strong public outreach program. The Committee understands that there are real economic costs to the recommendations contained in this report. For each recommendation there will of necessity be tradeoffs derived from the varying cost-effectiveness of different strategies.

The Committee makes four overarching recommendations:

Overarching Recommendation 1

The Committee recommends an integrated approach to the management of Nr. This approach will likely use a combination of implementation mechanisms. Each mechanism must be appropriate to the nature of the problem at hand, be supported by critical research on decreasing the risks of excess Nr, and reflect an integrated policy that recognizes the complexities and tradeoffs associated with the nitrogen cascade. Management efforts at one point in the cascade may be more efficient and cost effective than control or intervention at another point. This is why understanding the nature and dynamics of the N cascade is critically important.

Overarching Recommendation 2

The framing of the reactive nitrogen cascade provides a means for tracking nitrogen as it changes form and passes through multiple ecosystems and media. This complexity requires the use of innovative management systems and regulatory structures to address the environmental and human health implications of the massive amounts of damaging forms of Nr. It is difficult to create fully effective regulations de novo for such a complex system so we recommend utilizing adaptive management to continuously improve the effectiveness and lower the cost of implementation policies. This in turn will require a monitoring system that will provide feedback on the effectiveness of specific actions taken to lower fluxes and concentrations of Nr.

Overarching Recommendation 3

EPA should form an intra-Agency Nr management task force that will build on existing Nr research and *management capabilities within the Agency. This intra-Agency task force should be aimed at increasing scientific understanding of: (1) Nr impacts on terrestrial and aquatic ecosystems, human health, and climate,(2) Nr-relevant monitoring requirements, and (3) the most efficient and cost-effective means by which to decrease various adverse impacts of Nr loads as they cascade through the environment.*

Overarching Recommendation 4

Successful Nr management will require changes in the way EPA interacts with other agencies. To coordinate federal programs that address Nr concerns and help ensure clear responsibilities for monitoring, modeling, researching and managing Nr in the environment, the Committee recommends that EPA convene an Inter-agency Nr management task force. It is recommended that the members of this inter-agency task force include at least the following federal agencies: U.S. Department of Agriculture, U.S. Department of Energy, U.S. Department of Housing and Urban Development, U.S. Department of Transportation, National Oceanic and Atmospheric Administration, U.S. Geological Survey, U.S. Forest Service, and Federal Emergency Management Agency . This task force should coordinate federal programs that address Nr concerns and help ensure clear responsibilities for monitoring, modeling, researching, and managing Nr in the environment. The EPA Office of International and Tribal Affairs should work closely with the Department of State to ensure that EPA is aware of international efforts to control Nr and is developing national strategies that are compatible with international initiatives.

Similar recommendations for coordination and joint action among and between agencies at both state and federal levels have been made in the National Research Council's recent reports on the Mississippi Basin (NRC, 2008b, 2009). These intra and inter-agency Nr-management task forces should take a systems approach to research, monitoring, and evaluation to inform public policy related to Nr management. The Committee proposes that the intra and inter-agency task forces coordinate the following activities to implement a systems approach to Nr management.

Development of methods

Implementation of a systems approach will require development of methods to facilitate various aspects of Nr management. These include methods for: (1) establishing and evaluating proposed Nr budgets; (2) using life cycle accounting approaches for Nr management; (3) gathering and using data on N fertilizer use and other Nr sources and fluxes as the basis for informed policies, regulations and incentive frameworks for addressing excess Nr loads; (4) evaluating the critical loads approach to air and water quality management; (5) identifying and using indicators of excess Nr's economic damage and effects on human health and the environment; and (6) using systems-based approaches for controlling Nr releases to the environment.

Implementing best management practices (BMPs)

It will be necessary to improve the scientific understanding of BMPs that can be used for specific applications to manage Nr. In particular, this includes better scientific understanding of: (1) Nr requirements in agriculture to ensure adequate food, feed, fiber, and bioenergy feedstock supply while also avoiding negative impacts on the environment and human health; (2) Nr requirements for urban landscapes (e.g., residential and commercial) and their maintenance while avoiding negative impacts on the environment and human health; (3) planning and pollution prevention, including low impact development and natural ecosystem service preservation; (4) use of natural land features and attributes, such as wetland preservation and enhancement, natural soil profiles, and buffer strips; and (5) improved removal of Nr from sewage waste steams at both large-scale wastewater treatment facilities and individual subsurface (septic) systems. In addition, proactive extension and technology transfer approaches will need to be established to facilitate adoption of BMPs.

Developing appropriate tools and metrics for assessing impact from adoption of best management practices

Assessment activities will also be an important element of the systems approach to managing Nr. These activities should include: (1) quantifying the effectiveness and impact of policies and regulations focused on reduction of negative environmental impacts from Nr; (2) assessing combined carbon (C) and Nr effects on terrestrial and aquatic ecosystems; (3) assessing indicators/endpoints, costs, benefits, and risks associated with impairment of human health and decline and restoration of ecosystem services; (4) reviewing existing and proposed legislation for purposes of better integrating or designing regulatory activities that recognize the nitrogen cascade or streamlining procedures for enacting Nr risk reduction strategies; and (5) evaluating economic incentives, particularly those that integrate air, aquatic, and land sources of excess Nr.

Education, outreach, and communication

It will be necessary to develop new education, outreach, and communication initiatives. As discussed in this report, this includes a range of targeted outreach and education programs to manage Nr and achieve desired environmental outcomes.

6.3. Near-term Management Goals

The Committee puts forward four goals for actions that could be taken by EPA or other management agencies to decrease Nr entering the environment from various sources. We believe these goals can be attained over the near term (approximately 10-20 years) using existing and emerging technologies and practices. These suggestions, if implemented, have the potential to reduce total Nr loadings to the environment in the U.S. by approximately 25% below current levels. The Committee believes that these represent realistic and attainable near-term goals, however further reductions are undoubtedly needed for many N-sensitive ecosystems and to ensure that health-related standards are maintained. The Committee understands that actual policy decisions on the implementation of programs to limit Nr releases to the environment may differ from those listed below for a variety of reasons, but believes that an aggressive level of action, as represented by these goals, is critical given the growing demand for food and fiber production and energy use from population pressures and economic growth. The rationale for these goals is set forth below, along with recommended management options for achieving the goals.

Management Goal 1. Controls on NO_x emissions from mobile and stationary sources

The Clean Air Act (1970) and its Amendments (1990) have resulted in NO_x emissions that are less than 50 percent of what they would have been without existing controls. While this is an admirable accomplishment, there is still a need to seek improvements. NO_x emissions are an order of magnitude greater than at the beginning of the twentieth century. As a consequence, there remain significant negative impacts on both humans and ecosystems. In 2002, coal-fired utilities generated approximately 1.3 Tg N annually (see Figure 3). If all coal-fired plants used state-of-the-art NO_x controls, this number could be reduced by 0.6 Tg N/yr (calculations performed by Cohen, 2008); in fact, 2008 emissions have been reduced by 0.3 Tg N/yr from 2002 levels (see Figure 3), so in essence, half the reduction has already been accomplished. The EPA should continue to reduce NO_x emissions from major point sources, including electric generating stations and industrial sources, expanding the use of market mechanisms such as cap and trade. Under this scenario, it is likely that high-efficiency, low-emission power plants will be built for energy needs. Some controls on NO_x emissions are implemented only in the ozone season (May to September) (U.S. EPA 2009c). To protect welfare and avoid adverse effects on ecosystems, NO_x emissions controls should be implemented year round.

For mobile sources, emissions for highway and off-highway sources are approximately 2.2 Tg N/yr and 1.2 Tg N/yr, respectively. EPA is in the process of implementing a number of regulations that will reduce NO_x from mobile sources (see Appendix F). The implications of these recent regulations are not reflected in the quantitative analysis presented in this report. EPA projects future year decreases in emissions (see Figure 5 in Section 2.2.1). However, better controls are needed for on-road heavy duty diesel vehicles and off-road vehicles, which include locomotives, construction, farm, landscaping equipment, and marine vehicles. For these off-road vehicles, 80-90% NO_x removal is technically achievable (deNevers, 1995; Koebel et al., 2004). Assuming a 40% reduction for these sources, there is a potential reduction of 1.4 Tg. The total reduction for both mobile and stationary sources is then approximately 2 Tg N/yr. Part of achieving such levels of compliance will require the implementation of inspection and maintenance programs or road-side monitoring.

The Committee cautions, however, that achieving such a goal may be inadequate for many areas to meet the new 60 to 70 ppb ozone standard recommended by the EPA Clean Air Scientific Advisory Committee (CASAC) (U.S. EPA CASAC, 2008) or even the 75 ppb standard currently promulgated. Additional measures such as increasing the role of solar- and wind-generated electricity, wider use of hybrid and electric cars, and public transit conducive to energy conservation and reduced emissions should be promoted.

> **Management Goal 1.** *The Committee estimates that if EPA were to expand its NO_x control efforts for emissions of mobile sources and power plants and include implementation of year round controls on stationary sources to protect welfare and avoid adverse effects on ecosystems, a 2.0 Tg N/yr decrease in the generation of reactive nitrogen could be achieved. It is believed that coal-fired utilities could experience a reduction of 0.6 Tg N/yr. Since 2002, emissions have already been reduced by at least 0.3 Tg N/yr; hence, this represents an additional 0.3 Tg N/yr. Approximately 3.4 Tg N/yr can be attributed to mobile sources (highway, off-highway). Assuming a conservative 40% reduction, an additional 1.4 Tg N/yr could be reduced.*

Management Goal 2. Nr discharges and emissions from agricultural lands and landscapes

Section 5.3.4 of this report reviews the various methods that can be used to improve Nr management in agricultural systems. The Committee estimates that crop N-uptake efficiencies can be increased by up to 25% over current levels through a combination of knowledge-based practices and advances in fertilizer technology (such as controlled release and inhibition of nitrification). Crop output can be increased while reducing total Nr by up to 20% of applied synthetic fertilizers, approximately 2.4 Tg N/yr below current levels of Nr additions to the environment. These are appropriate management goals with today's available technologies. Further progress is possible through expanded research programs.

The Committee is concerned about current policies and practices governing biofuel development. Acreage devoted to corn production has increased substantially for corn based ethanol production during the past several years (with nearly one-third of the crop currently devoted to bioethanol production), with fertilizer nitrogen use on corn increasing by at least 10% (an additional 0.5 Tg N/yr), largely to meet biofuel feedstock crop demand. In the absence of Nr controls and a failure to implement best practices, current biofuels policies will make it extremely difficult to reduce Nr transfers to soils, water and air (Simpson et al., 2008). Integrated management strategies will be required.

The Committee also notes with concern the increase of N_2O in the atmosphere. The Committee believes that GHG emissions trading will provide both opportunities and challenges for mitigating Nr environmental and health impacts. Policies and regulations should consider how to reward reductions of N-related GHG. Biofuel subsidies that accurately account for Nr contributions to GHG emissions, certification of individual biofuel plants for GHG impact, and rewards for farmers who reduce N_2O emissions are examples of how an integrated strategy can reduce agricultural GHG impacts. For additional production of liquid biofuels beyond the grandfathered amount in the Energy Independence and Security Act (EISA), EPA has the power to exercise some controls on N_2O emissions through the life cycle GHG accounting requirements. It is the opinion of the Committee that Section 204 of the EISA calling on the Agency to adopt a life cycle approach to the assessment of future renewable fuel standards is a positive step toward a comprehensive analysis.

Section 5.3.4 of this report reviews methods of controlling Nr from landscape runoff through the use of natural or restored wetlands, urban areas, and through the use of best management practices. The Committee finds that flows of Nr into streams, rivers, and coastal systems can be reduced by approximately 20% (~1 Tg N/yr) through improved methods of landscape management and without undue disruption to human commercial and aesthetic activities.

Management Goal 2. *The Committee estimates that crop N-uptake efficiencies can be increased by up to 25% over current practices through a combination of knowledge-based practices and advances in fertilizer technology amounting to ~2.4 Tg N/yr below current amounts of Nr additions to the environment. The Committee further estimates that excess flows of Nr into streams, rivers, and coastal systems can be decreased by approximately 20% (~1 Tg N/yr) through improved landscape management and without undue disruption to agricultural production.*

Management Goal 3. Ammonia emissions from livestock management and manure handling

In spite of gains made over the last several decades in decreasing the amount of NO_x emitted from stationary and mobile combustion sources, the total amount of Nr released into the atmosphere has remained relatively constant. This is related to the essentially unregulated release of ammonia from livestock operations. As discussed in Section 2.2.3, at the present time, fewer livestock are required to produce more animal products than in the past. For example, since 1975 milk production has increased linearly at the rate of ~ 180 kg milk per cow /yr while milk cow herd population decreased at the rate of ~69,000 head per yr (i.e., the 60% greater amount of milk produced in 2006 compared to 1970 required 25% fewer cows). Animal inventories declined by 10% for beef brood cows from 36 million head in 1970 to 33 million head in 2006, and the inventory of breeder pigs and market hogs declined 8% from 673 million head to 625 million head in the same period, even with similar or greater annual meat production. These trends resulted from greater growth rates of animals producing more meat in a shorter amount of time. In 1970, broilers were slaughtered after 80 days on feed at 1.7 kg live weight, but by 2006 the average weight was 2.5 kg after only 44 days on feed. These trends in requiring fewer animals to produce more animal food products through improved diet and increased production efficiency will continue.

Implementation of improved methods of livestock management and manure handling and treatment to decrease NH_3 emissions that have been developed since 1990 will further decrease ammonia and other gases and odor emissions. For example, sawdust litter helps decrease NH_3 emissions from pig manure with 44-74% of manure N converted to N_2. Storage covers for slurry storage tanks, anaerobic lagoons, and earthen slurry pits decrease emissions from those containments. Anaerobic digestion in closed containment has been studied for many types of applications. Recent research demonstrates reduction in NH_3 emissions after a permeable cover was installed (e.g., a polyethylene cover decreased NH_3 emissions by ~80%). A well managed swine lagoon can denitrify approximately 50% of the excreted N to N_2. Recently engineered developments utilizing closed loop systems (Aneja et al., 2008a) substantially reduce atmospheric emissions of ammonia (> 95%) and odor at hog facilities. Based upon recently demonstrated reduction of NH_3 emissions from swine and poultry production, a moderate reduction of 50% from 1990 NH_3 emission estimates for swine and poultry production should be attainable (Table 17). Because of the larger land area involved in dairy and beef production and the lack of effort that has been exerted in mitigating NH_3 emissions, a more modest and reachable goal of decreasing NH_3 emissions by 10% through improvements in animal diet and manure management is proposed (Table 17).

Management Goal 3. *The Committee estimates that livestock-derived NH_3 emissions can be decreased by 30% (a decrease of 0.5 Tg N/yr) by a combination of BMPs and engineered solutions. This is expected to decrease $PM_{2.5}$ by ~0.3 μg/m^3 (2.5%), and improve health of ecosystems by achieving progress towards critical load recommendations. Additionally we estimate that NH_3 emissions derived from fertilizer applications can be decreased by 20% (a decrease*

Table 17: Estimates for potential decreases in NH_3 emissions from livestock manure in the United States

NH_3 Source	% of Total NH_3	Tg NH_3-N/yr emitted	Estimated Decrease of NH_3	
			%	Tg N/yr
Dairy	23.1	0.37	10	0.040
Beef	27.1	0.44	10	0.040
Poultry	27.5	0.44	50	0.220
Swine	17.5	0.28	50	0.140
Goat/sheep	1.6	0.03	10	0.003
Horse	2.9	0.05	10	0.005
Total	**100**	**1.61**		**0.45**

Estimate is based on livestock emissions of 1.6 Tg from Table 1.

of ~0.2 Tg N/yr), through BMPs that focus on improvements related to application rate, timing, and placement.

Management Goal 4. Discharge of Nr from developed lands and point sources

National loadings of Nr to the environment from public and private wastewater point sources are relatively modest in comparison with global Nr releases; however, they can be important local sources with associated impacts, especially in highly-populated watersheds. The Committee has estimated that sewage containing Nr from human waste contributes 1.3 Tg N/yr to the terrestrial inputs of nitrogen (Table 1).

The Committee has also estimated that turf fertilizer usage contributes 1.1 Tg N/yr to terrestrial inputs, a load that could potentially be cut by about one third (Section 2.2.4). The Committee did not provide estimates for general stormwater and nonpoint source runoff nitrogen load reductions specific to developed or urban areas – runoff concentrations and loads are highly variable reflecting geographic and climatic conditions throughout the U.S. and equally variable removal efficiencies from standard treatment BMPs. This is shown in a summary of the International Stormwater Best Management Practices Database (Geosyntec Consultants, Wright Water Engineers, Inc., 2008). However, most BMPs are effective because they provide the beneficial biochemical conditions of wetlands, the biophysical controls described in Section 5.3.4 and Appendix C. These benefits, and the application of BMPs, are recommended in overarching recommendation 4, as well as in the preceding Management Goal 2 as applied to agricultural lands. Similar stormwater and nonpoint source management benefits specific to developed lands should be anticipated with BMP application in those areas.

Denitrification processes as applied to human waste at sewage treatment plants are well-studied and growing in application. Performance of these engineered solutions, collectively referenced as biological nitrogen removal (BNR), can be more rigorously controlled than for stormwater and nonpoint source BMPs. Recent publications by the U.S EPA (2007f, 2008e,f) have summarized the state of and the capability for nitrogen removal, and have reported that technologies to achieve effluent concentrations of 3 mg total nitrogen per liter (TN/L) or less are readily available. However, plant capacity and design, wastewater characteristics, and climate conditions can all affect the ability of a facility to remove nitrogen. EPA's review of 2003-2006 data for 16 facilities that remove nitrogen to varying degrees found a range of final effluent TN concentrations of 1.0 to 9.7 mg/L, with an average of 5.6 mg/L. In general, very small facilities (<0.1 MGD) do not perform as well, with a final TN concentration ranging from 6-12 mg/L. Treatment performance varied and exceeded 5 mg TN/L at some of the facilities. Given these conditions, and performance uncertainties, it seems reasonable to conclude that removal efficiencies in the range of 40-60% below standard effluent nitrogen loads could be readily attained. Based on the human waste load of 1.3 Tg N/yr, this would yield a decrease in total nitrogen load of between 0.5 and 0.8 Tg/yr. Using data provided by Maryland Department of the Environment (2006) and the Connecticut Department of Environmental Protection (2007), two states that have promoted nitrogen removal technologies as solutions to coastal eutrophication, EPA (2007f) has constructed cost estimates of upgrading the performance of sewage treatment plants ranging from $990,000 to $1.74 million per MGD treated.

There are two funding sources of significance authorized in the CWA that are used to fund projects relevant to the control of Nr. Section 319 establishes state nonpoint source management programs to plan for and implement management measures that abate sources of nonpoint pollution from eight source categories, including both urban and agricultural sources; however, the CWA disallows use of 319 funds for NPDES permit requirements, so urban areas with stormwater permits do not qualify for Section 319 funding. Over the years, section 319 has made available, through 60% matching funds, over $1.6 billion in assistance. The much larger source of funding comes under Title VI of the CWA, which has provided over $24 billion (federal) for the construction of treatment facilities for point sources of wastewater over the past 20 years, although only a fraction of this amount has been dedicated to denitrification processes. Title VI "state revolving" loan funds can be used for stormwater management, as well as other water pollution management activities, but not all states have chosen to use funds beyond traditional sewage treatment plant infrastructure needs because of the large backlog of demand for those purposes.

In 2009, under the American Reinvestment and Recovery Act (ARRA), the CWA Clean Water State Revolving Fund (CWSRF) received a $4 billion boost for clean water infrastructure and the CWSRF for fiscal year 2010 was tripled over the prior years to two billion dollars. These additional funds not only provide for jobs creation, as intended by Congress, but provide states with resources to reduce the backlog of clean water projects, which also often include nutrient management needs. The ARRA funds also emphasized the use of CWSRF dollars for stormwater and nonpoint source management and energy savings under a "green infrastructure" requirement. A 20% set-aside for green infrastructure was a requirement of AARA CWSRF funding and was used widely for projects that included reductions in GHG emissions, land-based low impact development BMPs to reduce runoff and improve runoff quality, and other innovative practices to treat wastewater and runoff. A green infrastructure requirement is being continued in the fiscal year 2010 CWSRF allocation.

Management Goal 4. *The Committee recommends that a high priority be assigned to increasing funding for nutrient management. We estimate that a decrease in Nr emissions from human sewage of between 0.5 and 0.8 Tg N/yr can be achieved, with additional decreases likely with increased stormwater and nonpoint source BMP application support.*

6.4. Summary of Specific Findings and Recommendations Corresponding to the Four Study Objectives

In this report the Committee has provided specific findings and recommendations to assist EPA in its understanding and management of nitrogen-related air, water, and soil pollution issues. The specific findings and recommendations corresponding to each of the four study objectives are summarized below.

Study Objective #1: Identify and analyze, from a scientific perspective, the problems Nr presents in the environment and the links among them.

In general, the Committee finds that uncertainty associated with rapid expansion of biofuels, losses of Nr from grasslands, forests, and urban areas, and the rate and extent of denitrification have created the need to measure, model, and report all forms of Nr consistently and accurately. Addressing this need will decrease uncertainty in the understanding of the fate of Nr that is introduced into the environment and lead to a better understanding of the impacts of excess Nr on the health of people and ecosystems. This should be accomplished through a coordinated effort among cognizant federal and state agencies and universities.

The Committee recommends that EPA routinely and consistently account for the presence of Nr in the environment in forms appropriate to the medium in which they occur (air, land, and water) and that accounting documents be produced and published periodically.

Specific Findings:

- Rapid expansion of corn-ethanol production has the potential to increase N fertilizer use through expanding corn production and its associated N fertilizer inputs. Development of cellulosic ethanol industry will require cultivation for cellulosic crops, which will also require N fertilizer. Distillers grains are changing animal diets and affecting N recycling in livestock. Both have important consequences for the effective future management of Nr. (Finding #4 – also pertains to study objectives 2 and 4)
- Although total N budgets within all terrestrial systems are highly uncertain, Nr losses from grasslands and forests (vegetated) and urban (populated) portions of the N cascade appear to be higher, on a percent of input basis, than from agricultural lands. The relative amount of these losses ascribed to leaching, runoff, and denitrification are as uncertain as the N budgets themselves. (Finding #9)
- Denitrification of Nr in terrestrial and aquatic systems is one of the most uncertain parts of the nitrogen cycle. Denitrification is generally considered to be a dominant N loss pathway in both terrestrial and aquatic systems, but it is poorly quantified. (Finding #10 – also pertains to study objective 4)
- The Committee finds that there is a need to measure, compute, and report the total amount of Nr present in impacted systems in appropriate units. Because what is measured influences what we are able to perceive and respond to, in the case of Nr, it is especially critical to measure total amounts and different chemical forms at regular intervals over time. (Finding #13 – also pertains to study objective 4)

Specific Recommendations:

- The Committee recommends that EPA routinely and consistently account for the presence of Nr in the environment in forms appropriate to the medium in which they occur (air, land, and water) and that accounting documents be produced and published periodically (for example, in a fashion similar to National Atmospheric Deposition Program summary reports). The Committee understands that such an undertaking will require substantial resources, and encourages the Agency to develop and strengthen partnerships with appropriate federal and state agencies and private sector organizations with parallel interests in advancing the necessary underlying science of Nr creation, transport and transformation, impacts, and management. (Recommendation #13 – also pertains to study objective 4)
- EPA should work with USDA and universities to improve understanding and prediction of how expansion of biofuel production, as mandated by the 2007 EISA, will affect Nr inputs and outputs from agriculture and livestock systems. Rapid expansion of biofuel production has the potential to increase N fertilizer use through expansion of corn production area and associated N fertilizer inputs, and from extending cultivation of cellulosic materials that will also need N inputs. Current models and understanding are not adequate to guide policy on how to minimize impact of biofuel expansion on environmental concerns related to Nr. (Recommendation #4)
- EPA should join with USDA, DOE, and universities in efforts to ensure that the N budgets of terrestrial systems are properly quantified and that the magnitudes of at least the major loss vectors are known. (Recommendation #9 – also pertains to study objectives 2 and 4)
- EPA, USDA, DOE, and universities should work together to ensure that denitrification in soils and aquatic systems is properly quantified, by funding appropriate research. (Recommendation #10 – also pertains to study objective 4)

Study Objective #2: Evaluate the contribution an integrated N management strategy could make to environmental protection.

In general, the Committee finds that effective management of Nr in the environment must recognize the existence of tradeoffs across a number of impact categories involving the cycling of nitrogen and other elements. In addition, an integrated multi-media approach to monitoring Nr is needed.

The Committee recommends that EPA:

1. Develop a uniform assessment and management framework that considers the effects of Nr loading over a range of scales reflecting ecosystem, watershed, and regional levels. The framework should include all inputs related to atmospheric and riverine delivery of Nr to estuaries, their comprehensive effects on marine eutrophication dynamics and their potential for management
2. Examine the full range of traditional and ecosystem response categories, including economic and ecosystem services, as a basis for expressing Nr impacts in the environment, and for building better understanding and support for integrated management efforts.

Specific Findings:

- There has been a growing recognition of eutrophication as a serious problem in aquatic systems (NRC, 2000). The last comprehensive National Coastal Condition Report was published in 2004 (EPA, 2004) and included an overall rating of "fair" for estuaries, including the Great Lakes, based on evaluation of over 2000 sites. The water quality index, which incorporates nutrient effects primarily as chlorophyll-*a* and dissolved oxygen impacts, was also rated "fair" nationally. Forty percent of the sites were rated "good" for overall water quality, while 11% were "poor" and 49% "fair." (Finding #11)
- The Committee finds that reliance on only one approach for categorizing the measurement of Nr is unlikely to result in the desired outcome of translating N-induced degradation into the level of understanding needed to develop support for implementing effective Nr management strategies. (Finding #14)
- Effective management of Nr in the environment must recognize the existence of tradeoffs across impact categories involving the cycling of other elements, particularly carbon and phosphorus. (Finding #18)
- The Committee has determined that an integrated approach to monitoring that includes multiple media (air, land, and water) components and considers a suite of environmental and human concerns related to reactive nitrogen in the environment (e.g., Nr effects, climate change, human health) is needed. Some of the phenomena that presented in this report need more definition and verification. More importantly, however, as controls are brought to bear on Nr, improvements need to be measured to verify and validate successful management strategies. If the desired improvements are not realized as shown by the collected data, corrective measures will be required. Such an adaptive approach acknowledges the likelihood that management programs will be altered as scientific and management understanding improve. (Finding #20 – also pertains to study objective 3)

Specific Recommendations:

- The Committee recommends that EPA develop a uniform assessment and management framework that considers the effects of Nr loading over a range of scales reflecting ecosystem, watershed, and regional levels. The framework should include all inputs related to atmospheric and riverine delivery of Nr to estuaries, their comprehensive effects on marine eutrophication dynamics, and their potential for management. (Recommendation #11)

- It is recommended that the EPA examine the full range of traditional and ecosystem response categories, including economic and ecosystem services, as a basis for expressing Nr impacts in the environment, and for building better understanding and support for integrated management efforts. (Recommendation #14)
- The Committee recommends that the integrated strategies for Nr management outlined in this report be developed in cognizance of the tradeoffs associated with reactive nitrogen in the environment, consistent with the systems approach of overarching recommendations 2 and 3. Specific actions should include:
  - Establishing a framework for the integrated management of carbon and reactive nitrogen
  - Implementing a research program that addresses the impacts of tradeoffs associated with management strategies for carbon, reactive nitrogen, and other contaminants of concern
  - Implementing a research and monitoring program aimed at developing an understanding of the combined impacts of different nitrogen management strategies on the interchange of reactive nitrogen across environmental media. (Recommendation #18)
- In cooperation with the Department of Agriculture, U.S. Army Corps of Engineers, U.S. Fish and Wildlife Service, and the and the Federal Emergency Management Agency, the EPA should develop programs to encourage wetland restoration and creation, with strategic placement of these wetlands where reactive nitrogen is highest in ditches, streams, and rivers. The Agency should also address the means of financing, governance, monitoring, and verification. Such programs might be modeled on the Conservation Reserve Program or extant water quality and environmental trading programs, but need not be limited to current practices. (Recommendation #15e – also pertains to study objective 3)
- The Committee recommends that EPA initiate discussions and take action to develop a national, multi-media monitoring program that monitors sources, transport and transition, effects using indicators where possible, and sinks of Nr in keeping with the nitrogen cascade concept. This comprehensive program should build upon existing EPA and state initiatives, as well as monitoring networks already underway in other federal agencies such as the U.S. Geological Survey programs and the NADP effort. (Recommendation #20 – also pertains to study objective 3)

Study Objective #3: Identify additional risk management options for EPA's consideration.

In general, the Committee finds that a number of risk management actions should be considered to reduce Nr loading and transfer to the environment. The Committee recommends risk management actions that include farm-level improvements in manure management, actions to reduce atmospheric emissions of Nr, and interventions to control Nr in water management programs.

Specific Findings:

- Farm-level improvements in manure management can substantially reduce Nr load and transfer. There are currently very few incentives or regulations to decrease these transfer and loads, despite the existence of management options to mitigate. (Finding #6)
- Scientific uncertainty about the origins, transport, chemistry, sinks, and export of Nr remains high, but evidence is strong that atmospheric deposition of Nr to the earth's surface, as well as emissions from the surface to the atmosphere, contribute substantially to environmental and health problems. Nitrogen dioxide, NO_2, is often a small component of NO_y, the total of oxidized nitrogen in the atmosphere. The current NAAQS for NO_2, as an indicator of the criteria pollutant "oxides of nitrogen," is inadequate to protect health and welfare. NO_y should be considered seriously as a supplement or replacement for the NO_2 standard and in monitoring. Atmospheric emissions and concentrations of Nr from agricultural practices (primarily in the form of NH_3) have not been well monitored, but NH_4^+ ion concentration and wet deposition (as determined by NADP and NTN) appear to be increasing, suggesting that NH_3 emissions are increasing. Both wet and dry deposition contribute substantially to NH_x removal, but only wet deposition is known with much scientific certainty. Thus, consideration should be given to adding these chemically reduced and organic forms of Nr to the list of criteria pollutants. (Finding #8)
- Meeting Nr management goals for estuaries, when a balance should be struck between economic, societal, and environmental needs, seems unlikely under current federal law. Enforceable authorities over nonpoint source, stormwater, air (in terms of critical loads), and land use are not adequate to support necessary Nr controls. Funding programs are presently inadequate to meet existing pollution control needs. Furthermore, new technologies and management approaches are required to meet ambitious Nr control needs aimed at restoring national water quality. (Finding #12 – also pertains to study objective 4)
- Intervention to control Nr under most water management programs generally occurs in three ways:
  - Prevention or source controls
  - Physical, chemical or biological "dead ending" or storage within landscape compartments where it

is rendered less harmful (e.g., long-term storage in soils or vegetation; denitrification, primarily in wetlands; reuse)

- Treatment using engineered systems such as wastewater treatment plants or BMPs for stormwater and nonpoint source runoff

While most management programs focus on the third (treatment) approach, there are opportunities for combining the three that can be more effective and cost less. (Finding #15)

- The Committee finds that there have been persistent increases in the amounts of Nr that have been emitted into and retained within various ecosystems, affecting their functioning. Unless this trend is reversed, it will become increasingly difficult for many of these ecosystems to provide the services upon which human well-being depends. The Committee believes that there is a need to regulate certain forms of Nr to address specific problems related to excess Nr, and we believe that the best approach for an overall management strategy is the concept of defining acceptable total Nr critical loads for a given environmental system. (Finding #16 – also pertains to study objective 4)
- Current EPA policy (40 CFR Part 51, Clean Air Fine Particle Implementation Rule) discourages states from controlling ammonia emissions as part of their plan for reducing $PM_{2.5}$ concentrations. In this rulemaking (*Federal Register* 72(79): 20586-20667), EPA has stated that "ammonia reductions may be effective and appropriate for reducing $PM_{2.5}$ concentrations in selected locations, but in other locations such reductions may lead to minimal reductions in $PM_{2.5}$ concentrations and increased atmospheric acidity." Ammonia is a substantial component of $PM_{2.5}$ in most polluted areas of the U.S. at most times. While it is true that reducing NH_3 emissions might increase the acidity of aerosols and precipitation, the net effect of NH_3 on aquatic and terrestrial ecosystems is to increase acidity. After being deposited onto the earth's surface, NH_4^+ is, under most circumstances, quickly nitrified, increasing the acidity of soils and waters. The Committee is unaware of any evidence that NH_3 reduces the toxicity of atmospheric aerosols or that high concentrations of NH_3 occur naturally over any substantial area of the U.S. It has not yet been established which components of PM have substantive effects on human health but the total concentration of $PM_{2.5}$ correlates with morbidity and mortality, and NH_3 contributes to $PM_{2.5}$. The visibility, degradation, and other adverse effects associated with $PM_{2.5}$ are related to aerosol surface area or mass where NH_4^+ certainly plays a role. (Finding #17)

Specific Recommendations:

- A policy, regulatory, and incentive framework is needed and should be developed to improve manure management to reduce Nr load and ammonia transfer, taking into account phosphorus load issues. (Recommendation #6)
- EPA should re-examine the criteria pollutant "oxides of nitrogen" and the indicator species, NO_2, and consider adding chemically reactive nitrogen as a criteria pollutant and NH_x and NO_y as indicators to supplement the NO_2 National Ambient Air Quality Standards. (Recommendation #8a)
- The Committee recommends that monitoring of NH_x and NO_y begin as soon as possible to supplement the existing network of NO_2 compliance monitors. (Recommendation #8b)
- The Committee recommends that EPA reevaluate water quality management approaches, tools, and authorities to ensure Nr management goals are attainable, enforceable, and the most cost-effective available. Monitoring and research programs should be adapted as necessary to ensure they are responsive to problem definition and resolution, particularly in the development and enhancement of nitrogen removal technologies and best management practices, and continue to build our level of understanding and increase our ability to meet management goals. (Recommendation #12 – also pertains to study objective 4)
- To better address Nr runoff and discharges from the peopled landscape, the Committee recommends that EPA:
  - Evaluate the suite of regulatory and non-regulatory tools used to manage Nr in populated areas from nonpoint sources, stormwater and domestic sewage, and industrial wastewater treatment facilities, including goal-setting through water quality standards and criteria; and
  - Determine the most effective regulatory and voluntary mechanisms to apply to each source type with special attention to the need to regulate nonpoint source and related land use practices. (Recommendation #15a)
  - Review current regulatory practices for point sources, including both wastewater treatment plants and stormwater, to determine adequacy and capacity towards meeting national Nr management goals; and
  - Consider technology limitations, multiple pollutant benefits, and funding mechanisms as well as potential impacts on climate change from energy use and greenhouse gas emissions, including nitrous oxide. (Recommendation #15b)
  - Set Nr management goals on a regional/local basis, as appropriate, to ensure most effective use of limited management dollars; and
  - Fully consider "green" management practices such as low-impact development and conservation measures

that preserve or re-establish Nr removing features to the landscape as part of an integrated management strategy along with traditional engineered best management practices. (Recommendation #15c)

- The Committee recommends that the Agency work toward adopting the critical-loads approach concept in determining thresholds for effects of excess Nr on terrestrial and aquatic ecosystems. In carrying out this recommendation, the Committee recognizes that in many cases it will be necessary for the Agency to enter into new types of research, policy, and regulatory agreements with other federal, state, and tribal units based on cooperative, adaptive, and systemic approaches that derive from a common understanding of the nitrogen cascade. (Recommendation #16 – also pertains to study objective 4)
- The Committee recommends that the EPA presumption that NH_3 is not a $PM_{2.5}$ precursor should be reversed and states should be encouraged to address NH_3 as a harmful $PM_{2.5}$ precursor. (Recommendation #17)

Study Objective #4: Make recommendations to EPA concerning improvements in Nr research to support risk reduction.

The Committee has recommended research in key areas to support risk reduction. The Committee's recommendations include research to advance the understanding of: the quantity and fate of Nr applied to major crops; how to accelerate crop yields while increasing N fertilizer uptake efficiency; agricultural emissions of forms of Nr; atmospheric deposition of Nr; and the potential for amplification of Nr-related climate impacts.

Specific Findings:

- Crop agriculture receives 60% of U.S. annual new Nr inputs from anthropogenic sources (9.8 Tg from N fertilizer, 7.7 Tg from crop BNF versus 29 Tg of N anthropogenically introduced into the U.S. environment per year) and accounts for 58% (7.6 Tg) of total U.S. Nr losses from terrestrial systems to air and aquatic ecosystems, yet current monitoring of fertilizer use statistics by federal agencies is inadequate to accurately track trends in quantities and fate of N applied to major crops and the geospatial pattern by major watersheds. (Finding #1)
- Nr inputs to crop systems are critical to sustain crop productivity and soil quality. Moreover, given limited land and water resources, global population growth, and rapid economic development in the world's most populous countries, the challenge is to accelerate increases in crop yields on existing farm land while also achieving a substantial increase in N fertilizer uptake efficiency. This process is called "ecological intensification" because it recognizes the need to meet future food, feed, fiber, and energy demand of a growing human population while also protecting environmental quality and ecosystem services for future generations (Cassman, 1999). More diverse cropping systems with decreased Nr fertilizer input may also provide an option on a large scale if the decrease in Nr losses per unit of crop production in these diverse systems can be achieved without a decrease in total food production, which would trigger indirect land use change to replace the lost production and negate the benefits. However, crop cultivars and agronomic practices are changing rapidly, which changes N requirements, but current efforts in research, extension, and conservation programs on N management within these rapidly evolving systems are not adequate to meet the challenge of providing better information to increase NFUE. (Finding #2)
- Nitrous oxide emissions from the Nr inputs to cropland from fertilizer, manure, and legume fixation represent a large proportion of agriculture's contribution to greenhouse gas emissions, and the importance of this source of anthropogenic greenhouse gas will likely increase unless NFUE is markedly improved in crop production systems. Despite its importance, there is considerable uncertainty in the estimates of nitrous oxide emissions from fertilizer, and research should focus on reducing this uncertainty. (Finding #3)
- There are no nationwide monitoring networks in the U.S. to quantify agricultural emissions of greenhouse gases, NO, N_2O, reduced sulfur compounds, VOCs, and NH_3. In contrast, there is a large network in place to assess the changes in the chemical climate of the U.S. associated with fossil fuel energy production, i.e., the National Atmospheric Deposition Program/National Trends Network (NADP/NTN) which has been monitoring the wet deposition of sulfate (SO_4^{2-}), NO_3^-, and NH_4^+ since 1978. (Finding #5)
- Synthetic N fertilizer application to urban gardens and lawns amounts to approximately 10% of the total annual synthetic N fertilizer used in the U.S. Even though this N represents a substantial portion of total N fertilizer use, the efficiency with which it is used receives relatively little attention. (Finding #7)
- The biogeochemical cycle of Nr is linked to climate in profound but nonlinear ways that are, at present, difficult to predict. Nevertheless, the potential for significant amplification of Nr-related impacts is substantial, and should be examined in more complete detail. (Finding #19)

Specific Recommendations:

- The Committee recommends increasing the specificity and regularity of data acquisition for fertilizer application to major agricultural crops in terms of timing and sufficiently small application scale (as well as for urban residential and recreational turf) by county (or watershed) to better inform decision-making about policies and mitigation options for reducing Nr load in these systems, and to facilitate monitoring and evaluation of impact from implemented policies and mitigation efforts. (Recommendation #1)

- To obtain information on Nr inputs and crop productivity the Committee recommends that:
  - Data on NFUE and N mass balance, based on direct measurements from production-scale fields, be generated for the major crops to identify which cropping systems and regions are of greatest concern with regard to mitigation of Nr load, and to better focus research investments, policy development, and prioritization of risk mitigation strategies. (Recommendation #2a)
  - Efforts at USDA and universities be promoted to: (1) investigate means to increase the rate of gain in crop yields on existing farm land while increasing N fertilizer uptake efficiency, and (2) explore the potential for more diverse cropping systems with lower N fertilizer input requirements to the extent that large-scale adoption of such systems would not cause indirect land use change. (Recommendation #2b)
  - EPA work closely with the U.S. Department of Agriculture (USDA), Department of Energy (DOE), the National Science Foundation (NSF), and universities to help identify research and education priorities to support more efficient use and better mitigation of Nr applied to agricultural systems. (Recommendation #2c)
- The Committee recommends that EPA ensure that the uncertainty in estimates of nitrous oxide emissions from crop agriculture be greatly reduced through the conduct of EPA research and through coordination of research efforts more generally with other agencies such as USDA, DOE, NSF, and with research conducted at universities. (Recommendation #3)
- The status and trends of gases and particulate matter emitted from agricultural emissions (e.g., NO_3^- and NH_4^+) should be monitored and assessed utilizing a nationwide network of monitoring stations. EPA should coordinate and inform its regulatory monitoring and management of reactive nitrogen with the multiple efforts of all agencies including those of the U.S. Department of Agriculture and NSF-supported efforts such as the National Ecological Observatory Network (NEON) and the Long Term Ecological Research Network (LTER). (Recommendation #5)
- To ensure that urban fertilizer is used as efficiently as possible, the Committee recommends that EPA work with other agencies such as USDA as well as state and local extension organizations to coordinate research and promote awareness of the issue. (Recommendation #7a)
- Through outreach and education, supported by research, improved turf management practices should be promoted, including improved fertilizer application and formulation technologies and maintenance techniques that minimize supplemental Nr needs and losses, use of alternative turf varieties that require less fertilization, alternative ground covers in place of turf, and use of naturalistic landscaping that focuses on native species. (Recommendation #7b)
- EPA should pursue the longer term goal of monitoring individual components of Nr, such as NO_2 (with specificity), NO, PAN, and HNO_3, and other inorganic and reduced forms, as well as support the development of new measurement and monitoring methods. (Recommendation #8c)
- The scope and spatial coverage of the Nr concentration and flux monitoring networks (such as the National Atmospheric Deposition Program and the Clean Air Status and Trends Network) should be increased, and an oversight review panel should be appointed for these two networks. (Recommendation # 8d)
- EPA in, coordination with other federal agencies, should pursue research goals including:
  - Measurements of deposition directly both at the CASTNET sites and in nearby locations with non-uniform surfaces such as forest edges
  - Improved measurements and models of convective venting of the planetary boundary layer (the lowest layer of the atmosphere) and of long range transport
  - Improved analytical techniques and observations of atmospheric organic N compounds in vapor, particulate, and aqueous phases
  - Increased quality and spatial coverage of measurements of the NH_3 flux to the atmosphere from major sources especially agricultural practices
  - Improved measurement techniques for, and numerical models of, NO_y and NH_x species (especially with regard to chemical transformations, surface deposition and off-shore export and linked ocean-land-atmosphere models of Nr). (Recommendation #8e)
- Research should be conducted on: best management practices that are effective in controlling Nr, especially for nonpoint and stormwater sources (including land and landscape feature preservation); setting Nr management targets that realistically reflect these management and preservation capacities; and constructing a decision framework to assess and determine implementation actions consistent with management goals. (Recommendation 15d)
- The EPA should support cross-disciplinary and multiagency research on the interactions of climate and Nr. To determine the interactions of global biogeochemical Nr cycles and climate, the

Committee suggests that EPA follow a series of steps such as:

1. Select several likely scenarios for global climate from the IPCC report for the year 2050
2. Down-scale statistics or nest regional climate models within each of these global scenarios to generate meteorological and chemical fields (e.g., temperature, relative humidity, winds, precipitation, CO_2) for a few years around 2050
3. Run several independent biogeochemical Nr models (earth system models that include air/water/land) for North America for these years with current Nr and emissions and application rates
4. Rerun models with decreased Nr emissions/application to evaluate strategies for controlling impacts such as those described in this report. (Recommendation #19)

6.5 Conclusions and Observations

Nitrogen is not only an essential resource for humans, for example its use in food production, but also a byproduct of essential processes such as combustion. The increasing amounts of nitrogen that humans capture through the Haber-Bosch process for useful purposes and the increasing amounts of nitrogen released from combustion also add increasing amounts of excess reactive nitrogen (Nr) to the environment. In the United States, the production of crops receives 60% of the new Nr inputs from anthropogenic sources, but also accounts for almost the same proportion of total Nr losses from terrestrial systems to air and aquatic ecosystems. Nitrogen fertilizer use efficiency by crops seldom reaches 50% and may be 33% or lower. Fossil fuel combustion is another major contributor of excess Nr in the production of essential energy. However, the excess Nr that flows from these activities is not benign. There are serious negative impacts from excess Nr on both human health and the environment. Table 1 gives a range of examples of these.

The nature of the problem

Dealing with excessive reactive nitrogen is an extraordinarily complex issue. Part of this relates to the nature of nitrogen and its ability to change its form and flow through different media, as evidenced conceptually by the nitrogen cascade. Nitrogen's transformative nature only increases the difficulty of dealing with its negative aspects. Further, unlike the linear problems that society has been more accustomed to dealing with in the past, excessive Nr in the environment is in a class of problems sometimes characterized as "wicked" (Batie 2008, Kreuter 2004). For a "wicked" problem;

- There is not universal agreement on what the problem is – different stakeholders define it differently
- There is no defined end solution, the end will be assessed as "better" or worse"
- The problem changes over time
- There is no clear stopping rule – stakeholders, political forces and resource availability will make that determination on the basis of "judgments"
- The problem is associated with high uncertainty of both components and outcomes
- Values and societal goals are not necessarily shared by those defining the problem or those attempting to make the problem better

This is not to say that society does not try to deal with such problems (healthcare, environmental degradation, water resource management, food safety, etc.). What it does say is that different approaches are needed to deal with such problems as compared with better defined problems that are amenable to disciplinary linear science where experts can define the problem and its endpoint.

The Integrated Nitrogen Committee has provided a number of findings and recommendations with respect to the problems caused by excess Nr. Some of these respond to specific defined science based concerns. Others relate to broader concerns the Committee raised in dealing with the overall Nr dilemma. The following points synthesize some of the important lessons learned from the more than four years of study on this issue by the Integrated Nitrogen Committee.

Recognizing the problem and building consensus

It is critically important that the problems caused by integrated nitrogen be widely recognized. Many recognize that we add nitrogen to the environment for specific useful purposes. Fewer recognize that there are both direct and indirect impacts from this that damage both the environment and human health. Until there is general recognition that there is a problem and we need to deal with the negative externalities of excess reactive nitrogen in our environment, there will be no willingness to tackle this issue. Education, communication and outreach are critically important to engender in the public sufficient will to tackle this widespread problem. Education, communication and outreach will be critical to the formation of a common definition of the problem, an essential step once it is recognized. Following that, there will have to be some degree of public consensus for actions that will effectively reduce excess reactive nitrogen in the environment. These steps will not be possible unless there is a process of public consensus building with respect to Nr. The first essential step in trying to deal with a "wicked" problem is getting some measure of agreement across different participants and stakeholders about the problem itself.

The importance of the nitrogen cascade

Understanding the problem will require recognition of the nature of Nr. In this case, the Integrated Nitrogen Committee found the concept of the nitrogen cascade (pictured in the Executive Summary and Chapter 1) to be an essential guide to approaching the problem. This conceptual framework traces the flows of new nitrogen through atmospheric, terrestrial, and aquatic environmental systems where Nr is received, stored and passed on in one form or another. The Committee initially spent much of its effort on understanding these flows and then determining as best as possible the magnitudes of the flows and sinks through these systems. This is the critical baseline information needed to understand the problem, and many of the recommendations in this report relate to gaining a better understanding of this phenomenon. Unless it is well understand how Nr flows through these systems, what the Nr sinks are in these system components, and what the magnitudes are of both the sinks and flows, any attempts to better control Nr may well be ineffective. Understanding and being able to quantify the nitrogen cascade will allow the identification of the major excess Nr contributors, an understanding of the different forms of Nr at various points along the cascade, and enable the determination of more effective interdiction points. Without this basic understanding of the flows of Nr, their nature, and their magnitude, attempts to deal with excess Nr will have high uncertainty. Chapter 2 summarizes much of this critical information that the Committee was able to determine and assemble from other sources.

Integrated approaches are essential

Given what we know about the way Nr behaves, efforts to deal with excess Nr must be organized in a way that reflects the nature of the problem. Unfortunately, many of our approaches are narrowly disciplinary focused, and our policy and regulatory institutions are often focused on one or another media where excess Nr may temporarily reside or on a sector that contributes excess Nr. The regulatory structure that has evolved for problems affecting human health and the environment has been specifically narrow, following policymakers focus on such things as clean water or clean air. These silos have to be broken down if excessive Nr is to be dealt with effectively. Current efforts by EPA and other agencies to encourage more integration across these silos, and include other institutions and stakeholders, are absolutely essential. Research efforts to better understand excess Nr and better mitigate its negative impacts must be trans-disciplinary. What will also be critical is greatly increased collaboration and cooperation among and between agencies and interested stakeholders. Several of the Committee's recommendations address this issue, calling for formal mechanisms to encourage this to take place. The Nr problem has boundaries much broader than the boundaries of the institutions that we have relied on in the past to protect human health and the environment. We are not going to be effective if we do not both expand these boundaries and adopt a broad multi-institutional reach.

Essential monitoring and research

In the effort to understand and quantify the nitrogen cascade the Committee became aware of areas of needed research and monitoring. Much of this is essential for improving our knowledge of what goes on in the cascade. It is also essential for benchmarking current Nr flows and sinks and for targeting where actions are best taken to reduce excess Nr. There is not sufficient information and understanding of these flows and sinks to allow maximum benefit from utilizing the full power of the cascade concept. The Committee has recommended improved monitoring and research to enhance our understanding in air, land and water environments. In some cases our knowledge has such wide margins of error that we cannot identify or quantify important concentrations or flows sufficiently for necessary decisions. In other cases we need much better understanding of the efficacy of actions that might be taken to control Nr. In some cases we need to know more about the indirect impacts of Nr as well as the indirect impacts of measures to control Nr. Monitoring is both an essential part of the research needs as well as being a critical guide to what we face and whether our efforts to better control Nr are being effective. Such environmental monitoring is often not considered to be critically important. It is critically important for effective approaches to reducing excess Nr.

Where to begin

The approach taken in this report and its recommendations should result in helping enable the control of excess Nr to proceed on the basis of starting where it is most technically and economically effective. Some of this may be low hanging fruit, or particular niches where institutions and stakeholders already have a common purpose. Part of the value of the nitrogen cascade is that its characterization of Nr sinks and flows allows the comparison of alternative points of entry and interdiction. Further monitoring and research should also allow the comparison of different modes of interdiction. There will be choices to be made between preventing increased Nr at the source, stabilizing it, or treating the medium involved to remove it. Additional research and actual experience in such efforts, coupled with monitoring, will be essential for making these choices. One product of the cascade exercise is a better understanding of what and where the major contributors of Nr are. The big sources of Nr have to be addressed if there is to be meaningful impact on reducing excess Nr. Part of the decision about where to begin will relate to the efficacy of measures to reduce excess Nr, and our knowledge is by no means complete on this. Beyond the technical considerations of effectiveness, there will have to be policy decisions about the trade-offs and interdependencies between approaches such as market mechanisms, regulation, incentives, and voluntary actions. Market mechanisms generally require regulations that are the basis for the creation of the market situation that makes such things as emission trading viable. Voluntary actions are more likely if there is some prospect of future required action.

Metrics matter

What is measured is critical to determining the dimension of the problem, what to tackle, and whether progress is being made. Kilograms removed (or prevented at the source), the percentage of Nr removed from a particular cascade or sink, or dollars of damage avoided by the removal of Nr are all reasonable measures to use. Measuring the improvement in physical units of Nr can lead to very different source targets, control measures and estimations of success as compared to measuring dollars of damage. This relates to the dilemma presented by "wicked" problems in both the original problem definition and the determination of whether actions have made things better or worse. An example from the Chesapeake Bay is cited in the report that illustrates this. If the goal is less Nr in the bay waters, then all sources are important. If one is concerned about reducing the economic damage of Nr and uses dollars of damage, then atmospheric deposition becomes the primary focus because of the high value of health damages from atmospheric pollution related to Nr.

Setting goals for action

Finally, nothing is going to be accomplished if goals are not set and efforts do not get underway. There are sufficient findings and recommendations presented by the Committee in addition to what we already know to enable multiple agencies to begin to reduce the excess Nr entering the environment. Some of the trade-offs between alternative approaches are also well known. The Committee suggests actions that might be taken by EPA or other management authorities to reduce nitrogen in the environment and a 25% reduction of excess Nr is suggested as attainable with current technology over the near term. Actions being suggested need testing, refining and require monitoring. A start, even on a pilot scale, in one portion of the cascade or sector will yield valuable information about the efficacy of the approaches used, further demonstrate the necessity for a multi-agency joint stakeholder approach, and help further define the problem and where it can initially be best addressed. This necessity of getting underway is one of the main recommendations of the National Research Council's series of reports on improving water quality in the Mississippi (National Research Council, 2008b and 2009). These reports also emphasize the institutional arrangements that are necessary. These are also echoed in this report. Following on the National Research Council's reports, the USDA Natural Resources Conservation Service has recently begun an effort that targets nutrient reductions in the Upper Mississippi. It is time to get more efforts underway with effective collaboration between public and private institutions and stakeholders.

Because this report addresses the needs of EPA's research mission, there is substantial emphasis on gaps in knowledge about Nr and the research that needs to be done to fill these gaps. However, the report contains an extensive knowledge base about Nr which was a necessary precursor to addressing the objectives of the report. The report then identifies the problems posed by Nr, assesses the necessity of an integrated strategy to deal with these problems, identifies some risk management options for EPA's consideration, and makes recommendations for improved research and monitoring to support risk reduction. This information is sufficient to allow initial determinations of where and how the Nr problem can be addressed effectively with positive results. As efforts progress, more will be learned and improved methods, targeting, and analysis can be applied to this truly wicked problem.